Dynamical Studies In Hurricane Intensity Change

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LONG-TERM GOALS AND OBJECTIVES

The long-term goals and objectives of this research are to develop a physical understanding of tropical cyclone (TC) intensity change processes. Towards this goal, this year's work focused on two main areas: asymmetric dynamics of the TC inner-core region and vortex spin down over the open ocean. The following pages summarize pertinent milestones in each area.

- **Wavenumber One Inner-Core Instability in Hurricane-like vortices:**

APPROACH

Smith and Rosenbluth (1990) showed that two-dimensional vortices that posses an angular velocity maximum other than at the center axis are susceptible to an algebraic instability whose amplitude grows as the square root of time. This type of angular velocity profile is typical for hurricanes because of their low vorticity centers (the eye), but their susceptibility to this type of instability has not yet been investigated.

WORK COMPLETED, RESULTS, IMPACT, AND APPLICATIONS

Using both linear and nonlinear models, we have shown that a two-dimensional vortex with a hurricane-like tangential velocity profile exhibits this instability, and that the growth rates are quite substantial. The instability manifests itself as a growing wobble of the vortex core, and at finite amplitudes the wobble induces secondary, higher-wavenumber instabilities in the near-core region (See Figure 1). This growing wobble also tries to eject low vorticity from the vortex center, similar to the processes observed by Schubert et al. (1999), even in the absence of exponential instability. Through careful study of the phenomenon we determined that the instability is caused by a resonance between a rotating discrete neutral Rossby wave in the vortex core (whose radial structure describes the displacement of the core) and sheared vortex-Rossby waves that are trapped in the vicinity of the angular velocity maximum. In the immediate future we plan to investigate whether the instability can be realized in more realistic models (e.g., shallow water, asymmetric balance, primitive equations, etc.).

- **Vortex Dynamics Under Axial Stretching:**

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APPROACH

The most intense atmospheric vortices, such as hurricanes and tornadoes, are initiated and maintained by convection. This convection induces low-level convergence, which continuously amplifies the local vertical vorticity and sustains the vortex against the effects of dissipation. Inspired by the general observation that both hurricanes and tornadoes are the most stable when they are intensifying, we have investigated the effect of convergence on vortex stability.

WORK COMPLETED, RESULTS, IMPACT, AND APPLICATIONS

We have used a numerical model of three-dimensional, incompressible, inviscid fluid flow based on three-dimensional vortex methods, which offer the advantages of having no inherent numerical dissipation and great computational efficiency. Using this model, we were able to simulate the dynamics of both stable, strongly perturbed vortices, and unstable vortices, under the effects of axial stretching. In both types of vortices, we found that the stretching and radial inflow associated with the surrounding deformation field suppressed the growth of disturbances and slowed the development of turbulence. While the stabilizing effect of the axial stretching is not overwhelming, the work has significant theoretical and practical implications regarding the stability of intense atmospheric vortices.

- **Hurricane Intensification in an Operational Forecast Model:**

APPROACH

The numerical output from the Geophysical Fluid Dynamics Laboratory (GFDL) Hurricane Prediction System (Kurihara et al., 1998) simulation of Hurricane Opal (1995) was analyzed using software developed at CSU. Opal intensified to hurricane status in the southern Gulf of Mexico then traversed the Gulf, quickly intensifying to a 125 kt storm by 0000 UTC 4 October. Opal fortunately weakened prior to landfall on the Florida panhandle the next morning. The GFDL model simulated this storm fairly well capturing the observed phase of intensification and weakening prior to landfall. Our research focus has been to examine the environmental and internal factors that regulated the intensity of Hurricane Opal and to develop a software package for analyzing the data that can be readily extended to other hurricane datasets generated by either the GFDL model (see Figure 2) or by other models.

WORK COMPLETED, RESULTS, IMPACT, AND APPLICATIONS

A mean tangential wind budget was performed for comparison with the results of Molinari et al. (1998) and Challa and Pfeffer (1990), who propose that eddy momentum fluxes aloft place a balanced vortex out of balance. The vortex responds by lifting air near its center in order to restore balance. By this theory the resulting uplift would then aid convection. Preliminary results verify the presence of positive eddy momentum fluxes aloft in the GFDL Opal simulation and are also suggestive in the role of convection in maintaining the vortex, yet a full attribution analysis will be needed to rigorously test the theory. In light of research by Bosart et al. (1999) on the possible role of a jetstream and mid-latitude trough to the north of Opal in the intensification of Opal, the divergence pattern aloft from the GFDL model was compared to their satellite-based measurements. After verifying a resemblance between the two divergence fields, our analysis showed that the GFDL divergence pattern is more strongly associated with a convective line far from the storm over the United States than with the hurricane over the Gulf of Mexico. Subject to the accuracy of the GFDL model, it has been demonstrated that the GFDL operational simulations can serve as a bridge for theories and forecasts based on environmental parameters.

- **Vortex Spin Down:**

APPROACH

As a foundation for ongoing work examining the life cycle of secondary eyewalls in hurricanes we have completed our study of the hurricane spin-down problem subject to a quadratic drag law in the surface layer.

WORK COMPLETED, RESULTS, IMPACT, AND APPLICATIONS

The time-dependent theory of Eliassen and Lystad (1997) serves as a useful basis for the geophysical spindown problems. The theory has been tested with the assistance of an axisymmetric Navier-Stokes numerical model. The numerical experiments broadly confirm the theoretical predictions for a range of vortex heights, maximum tangential wind speeds, constant and variable drag coefficients, and vortex sizes considered relevant for tropical storm and hurricane strength vortices. The theory is shown to furnish a consistent description of the weakening phase of two hurricanes observed by research aircraft. Despite the idealizations employed to yield a tractable model, the theory appears useful in elucidating weakening episodes of hurricanes not associated with strong asymmetries.

TRANSITIONS

During FY2000 it is anticipated that an algorithm for synthetically adding or removing PV anomalies in the GFDL hurricane model will be developed. This will allow testing of whether observed PV anomalies in the hurricane environment contribute to strengthening or weakening the simulated storm and will provide useful insight into simulated intensity change events. In addition, we have begun a new study of inner-core vorticity mixing using the RAMS model, which will shed new light and understanding on the physics of hurricane intensity change in association with polygonal eyewalls and hurricane mesovortices.

RELATED PROJECTS

Dominique Möller (University of Munich) and I are currently examining the dynamics of continuously stratified three-dimensional vortex Rossby waves in hurricane-like vortices using the three-dimensional Asymmetric Balance (AB) model developed by both of us during her post doctoral work at CSU. Work is also underway to develop a diagnostic package for PV inversion in hurricane-like vortices using the AB theory.

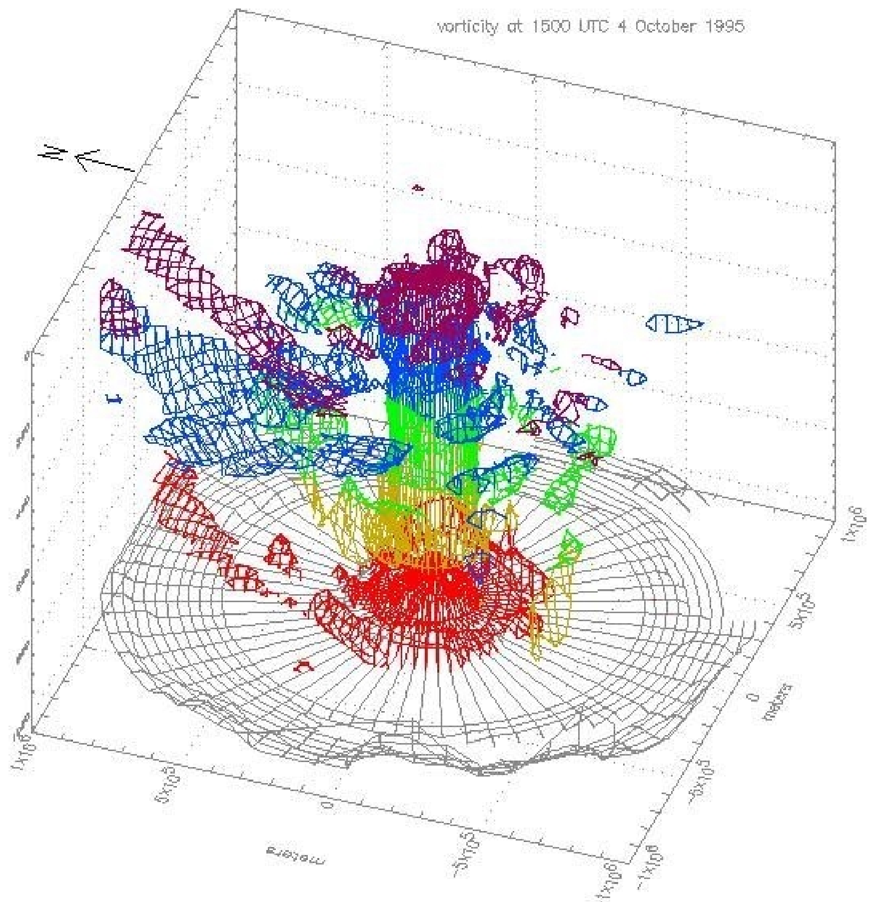
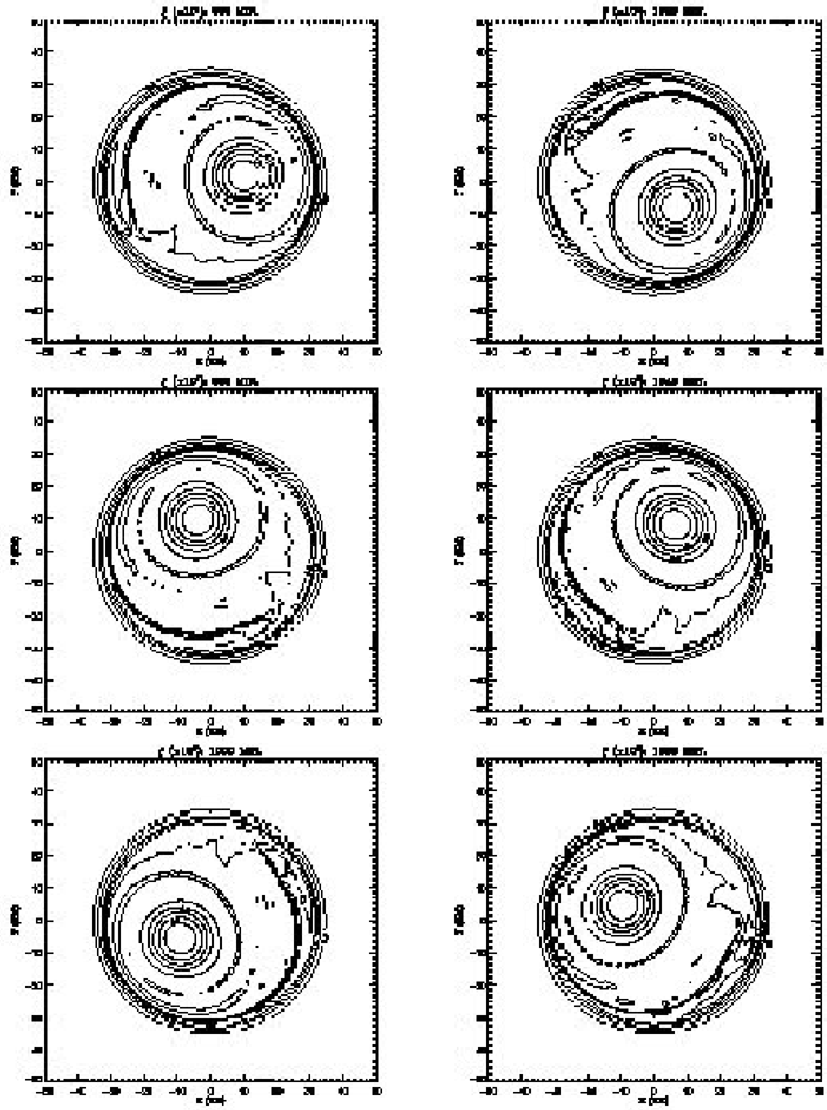


Figure 1: The 1.15 x 10^{-4} s^{-1} iso-surface of absolute vertical vorticity at 1500 UTC 4 October 1995. Colors denote vertical layers. Red – 1000 to 800 mb. Yellow – 800 – 600 mb. Green – 600 to 400 mb. Blue – 400 to 200 mb. Purple – above 200 mb. Gray represents the ground. Distances are in meters.



This sequence of images shows contours of vertical vorticity every 20 minutes in a hurricane-like vortex in which the wavenumber one algebraic instability has been excited. The low vorticity core, which was originally in the center, is now wobbling around the center axis. The wobble also increases gradients in the eyewall region, resulting in secondary instabilities.

Figure 2: See caption in the figure.

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- Refereed publications during FY-1999:

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- Non refereed publications during FY-1999:

Möller, J. D., M.T. Montgomery, 1999: Hurricane evolution via potential vorticity asymmetries in a three-dimensional asymmetric model. Presented at the 79th AMS Annual Meeting/23rd Conference on Hurricanes and Tropical Meteorology, Dallas.

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